Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Study on the Metal Fiber Filter Modeling for Capturing Radioactive Aerosol

Seunguk Lee, Chanhyun Lee, Minchan Park, Jaekeun Lee *
EcoEnergy Research Institute, Busan, 12 60-Street Gwahaksandan 1-ro, Gangseo-gu, Korea, 618-230
**Corresponding author: jklee@pusan.ac.kr*

1. Introduction

An Air cleaning system in Nuclear Power Plant is to deliver sufficient quantities of clean air to the control room so that operators can perform their assigned duties in comfort and safety. During an accident situation, the control room air cleaning system must continue to function and provide a habitable environment for the operators. The components of air cleaning system are demisters to remove entrained moisture, pre-filters to remove the bulk of the particulate matter, high efficiency particulate air (HEPA) filters, iodine absorbers(generally, activated carbon) and HEPA filters after the absorbers for redundancy and collection of carbon fines. The HEPA filters are most important components to prevent radioactive aerosols from being released to control room and adjacent environment.

The Conventional HEPA filter has pleated media for low pressure drop. Consequently, the filters must provide high collection efficiency as well as low pressure drop. Unfortunately, conventional HEPA filters are made of glass fiber and polyester, and pose disposal issues since they cannot be recycled. In fact, 31,055 HEPA filters used in nuclear facilities in the U.S are annually disposed [1].

The Rocky Flats Plant was a United States nuclear weapons production facility near Denver, Colorado, caused radioactive contamination within and outside its boundaries. The contamination primarily resulted from two major plutonium fires in 1957 and 1969. HEPA filters in the plants were easily burned by the fire and lost its filtering capacity [2].

Fig. 1. Damaged HEPA Filter Units from Fire [2]

There is a strong need to study and develop metal fiber filters that can be reused and meet the performance standards of current glass fiber HEPA filters while withstanding the harsh conditions posed by nuclear facilities. In this study, the metal fiber filter modeling that developed verifies to compare with experiment.

2. Methods and Results

2.1 Test Media for Modeling and Experiment

The Test metal fiber media used in this experiment is made of 316L stainless steel. That media consist of 8 μm metal fiber and have 0.53 and 1.59 in thickness. A physical characteristic of the media is given by table 1. The solidity of the media is calculated by the media mass, the media fiber diameter and the density of the metal fibers. The calculation result is about 0.24. These physical characteristics are used as input parameters for the filter efficiency and pressure drop modeling.

Table 1. Physical Specification of the Test Media

	Specification
Material	STS 316L
Material density(g/cm^3)	7.98
Filter size(mm)	150×150
Filter thickness(mm)	0.53, 1.06, 1.59
Fiber diameter(μm)	8.0
Filter solidity	0.24

2.2 Modeling Procedure

Fig. 2 shows a flow chart of the modeling procedure for aerosol filtration. The flow chart consists of four primary parts which include inputting basic conditions, calculating important non-dimensional variables, computing different single fiber collection efficiencies and calculating the total collection efficiency.

The first step in modeling procedure is to decide on the input variables by carefully considering the particle conditions, filter conditions and flow conditions. Next, secondary factors are derived based on the assumptions made and using the input variables from the previous step. From these secondary factors, single fiber collection efficiency can be computed. Lastly, using the calculated single fiber collection efficiency and all the initial inputs, the total collection efficiency can finally be estimated. Although standard temperature and pressure are typically used to calculate the efficiency of particle collection filters, actual temperature and pressure normally observed in nuclear power plants are used to calculate physical properties such as viscosity and mean free path for simulation inputs.

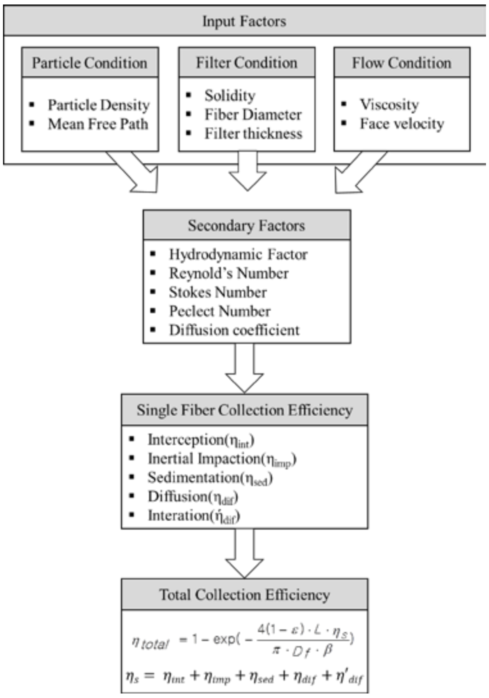


Fig. 2. Flow Chart of the Modeling Procedure

2.3 Experiment Procedure

Fig. 3 shows the schematic diagram of the filter test system. This system consists of five primary components that include an aerosol generation system; an aerosol concentration detector; an airflow rate measuring system; pressure gauges; and a test filter unit. The aerosol generation system consists of an atomizer, a diffusion dryer, and a particle charge neutralizer. The atomizer is used for generating polystyrene latex (PSL) aerosols and the generated aerosols pass through the diffusion dryer to remove moisture. The test aerosols then passes through a Kr-85 charge neutralizer to reduce the particle charge to the Boltzmann charge distribution. Test particles in the size range of 0.3 to 1.0 μm are used to evaluate the collection efficiency.

Aerosol concentrations upstream and downstream of the test filters were measured with particle counters (HIAC/ROYCO Inc., FE-80), which are capable of measuring the concentration of particles between 0.3 and 25.0 μm in size with maximum concentration range at 106 particles/ft^3. The measured upstream and downstream concentrations were later used for efficiency calculation. The airflow rate through the test filter was measured using differential pressure drop of the orifice. For each test condition, three filter face velocities, 1, 5, and 10 cm/s were used. The differential pressure drops across the test filters were measured with a micro-manometer (Furness Corp., FCO51) capable of measuring between 20 and 20,000 Pa with resolution of 0.001 Pa.

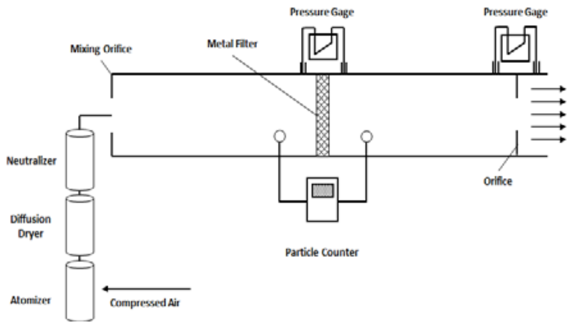
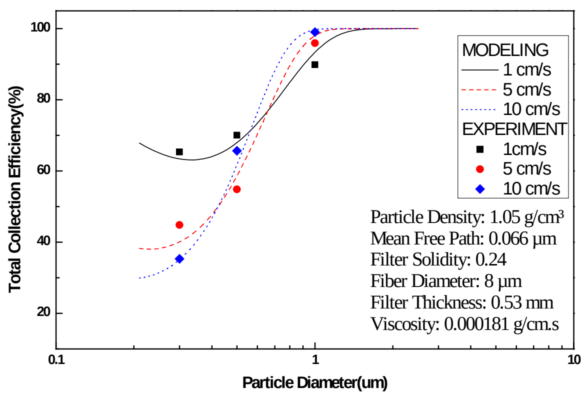


Fig. 3. Schematic Diagram for Measuring the Performance of the Metal Fiber Filter

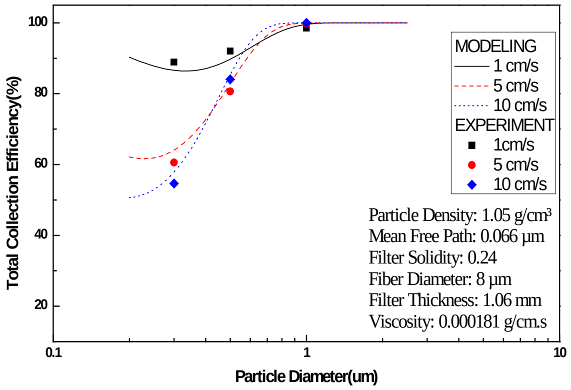
2.4 Results of Modeling and Experiment

Fig. 4 shows the further comparison between experimental and theoretical results investigating the effect of filter thickness and face velocity on the filter efficiency as a function of particle size. For the most part, the experimental result matched closely with the predicted values by simulation and the accuracy improved more as the filter thickness increases. The filtration efficiency of the metal fiber filter is found to be 98.6% for the 1.0 μm PSL test particles, and the pressure drop is 100.6 Pa for the face velocity of 10.0 cm/s with thickness 0.53 mm.

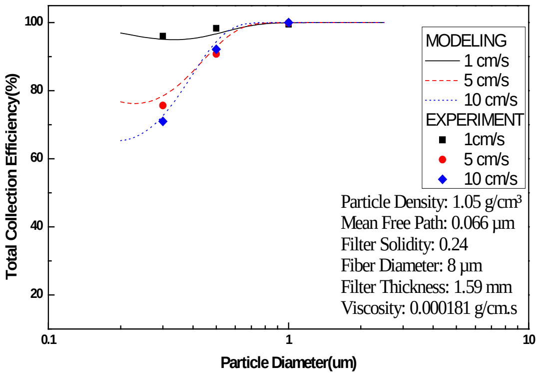
From the correlation analysis between the model and experiment, a good agreement with R^2 value of 0.999 is found at the face velocity of 5 cm/s indicating good reliability of the model. An R^2 is a statistic used in the theoretical models that main purpose is either the prediction of future outcomes or the testing of hypotheses. That is a statistical measure of how well regression line approximates the experiment data. An R^2 of determination ranges from 0 to 1. The coefficients of 1 mean that the regression graph absolutely fits the data.



(a) Filter Thickness: 0.53 mm



(b) Filter Thickness: 1.06 mm



(c) Filter Thickness: 1.59 mm

3. Conclusions

The Analyses at face velocities 1cm/s and 10cm/s are also carried out, and they also show R^2 value of 0.995. However, since official HEPA filter standards are established at face velocity of 5cm/s, this value will be used in further analysis. From the comparative studies carried out at different filter thickness and face velocities, a good correlation is found between the model and the experiment according to Fig. 4. As a matter of fact, a consistent R^2 value is observed across analyses carried out at the same face velocities at different filter thicknesses indicating high reliability of the model in predicting the filter characteristics at varying filter thickness.

REFERENCES

[1] Bergman, W., G. Larsen, R. Lopez, K. Wilson, C. Witherell and M. McGregor, Further Development of the Cleanable Steel HEPA Filter, Cost/Benefit Analysis, and Comparison with Competing Technologies, DOE/NRC Nuclear Air Cleaning and Treatment Conference, 24th, p. 708-742, 1997

[2] U.S. Department of Energy, Nuclear Air Cleaning Handbook. U.S. Department of Energy Washington, 2003